Detailed Investigation of the Gamma-Ray Emission in the Vicinity of SNR W28 with Fermi Large Area Telescope

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Fermi Gamma-ray Space Telescope

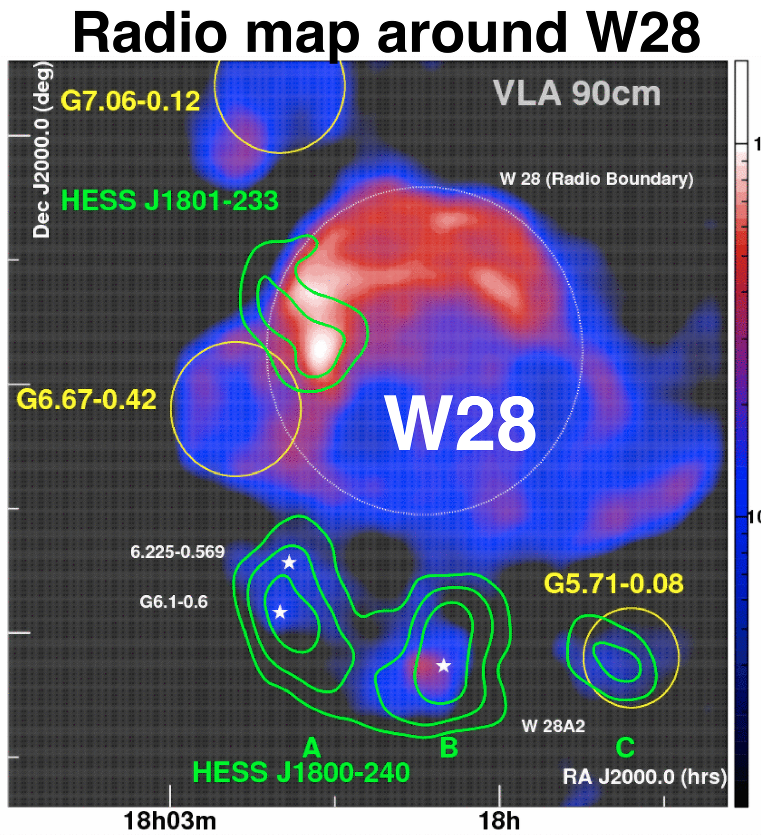
Abstract: We present a detailed investigation of the region around the supernova remnant (SNR) W28 with Fermi-LAT. There are three TeV sources located outside the boundary of the SNR, overlapping with molecular clouds (MCs). We investigated the spatial correlation of the GeV emission with the TeV sources and found good correspondences of the morphologies. With the wide-band gamma-ray spectra, these emissions can be naturally explained by a single model in which the cosmic-ray (CR) diffusion coefficient around W28 is smaller than the theoretical expectation in the interstellar space. The total energy of the CRs escaping from W28 is constrained through the modeling to be larger than 2×10^{49} erg, in agreement with the conjecture that SNRs are the main accelerator of the Galactic CRs.

I. Introduction

Spectra of escaped CRs are useful to estimate the CR acceleration in young SNRs.

‣**Important to understand the diffusion process of CRs.**

Radio map around W28



Green contours: TeV gamma-ray excess at 4, 5, and 6σ levels.

SNR W28

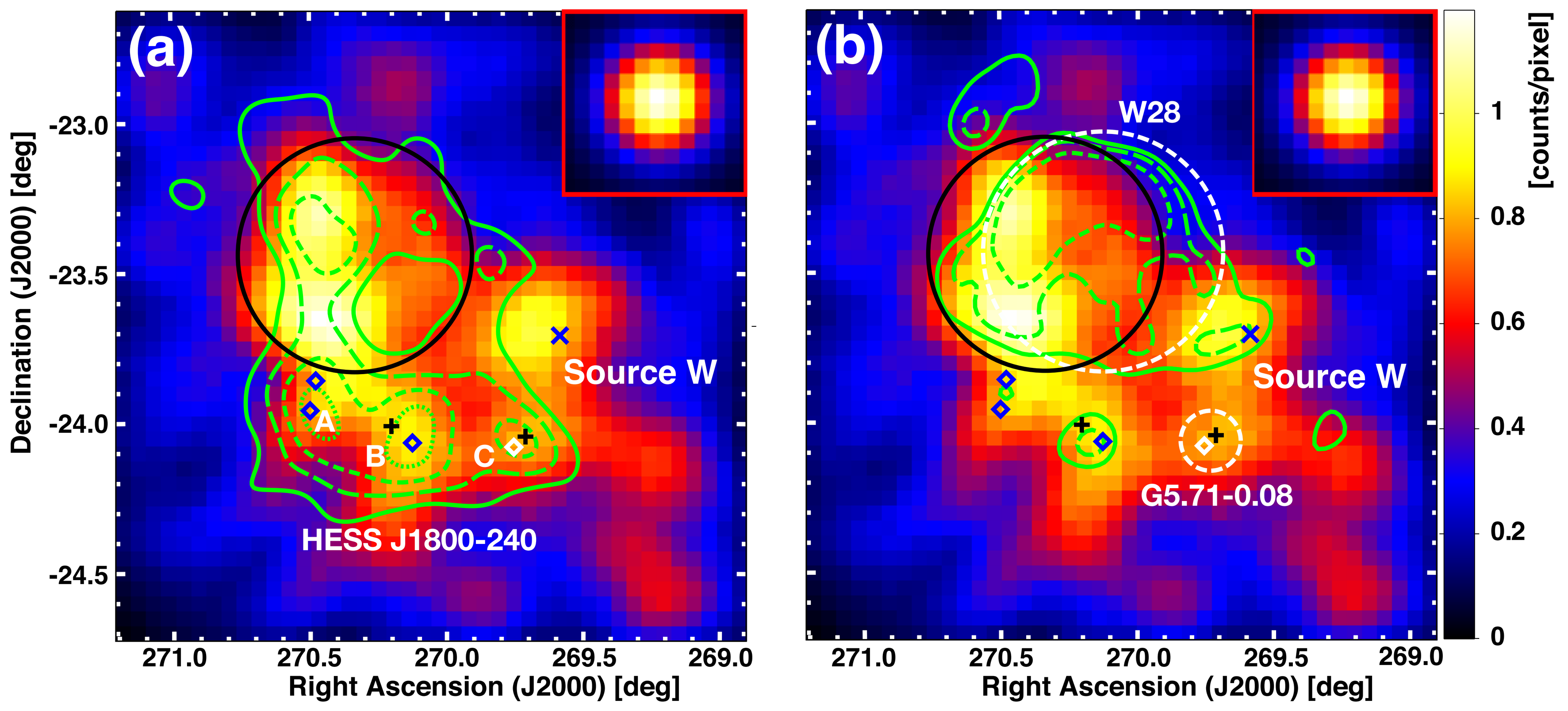
- Surrounded by giant MCs
- Age: 4×10^4 yr
- Gamma rays naturally explained by π^0 decays (Abdo et al. 2010).
- Three HESS sources outside W28 (Aharonian+08)
  - ‣Might come from the escaped CRs.
- Two GeV sources in the south region (Nolan et al. 2010).

We can tightly constrain the diffusion process of CRs by investigating the relation between the GeV and TeV emissions.

II. Morphological Analysis

Data Set Time Range: 2008/08/04 - 2012/08/04 (48 months)
IRFs: P7SOURCE_V6

The data in the 10-100 GeV band was used to take advantage of optimal angular resolution (< 0.2°) and weaker Galactic diffuse emission



Contours: TeV significance map at 20, 40, 60, and 80%(Aharonian et al. 2008)

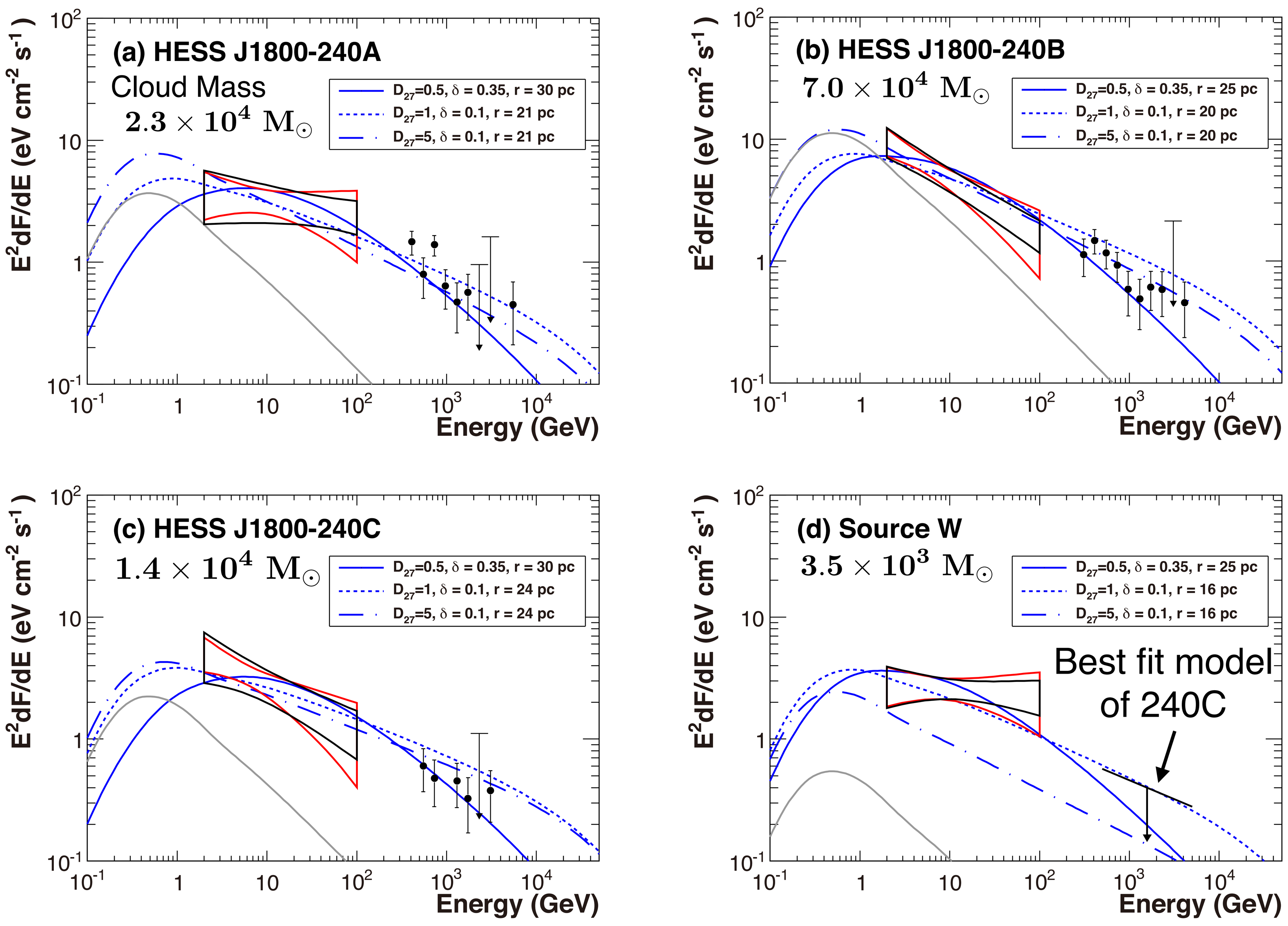
Contours: VLA 90cm image at 5, 10, and 20% of the peak intensity (Brogan et al. 2006)

◯, +: 2FGL sources ♢(White): OH maser spot ♢: HII regions X: Source W

‣ Source W is a newly detected point source. It is located outside the boundary of the TeV emission and overlap with radio emission of W28.

‣The GeV emission except for W28 itself can be well represented with the TeV significance map and Source W.

III. Spectral Results and Discussion



Red: Statistical error at 68% confidence range.
Black: Combined systematic errors due to uncertainties of LAT effective area, morphologies and interstellar emission model.

‣The GeV spectra of HESS J1800−240B and C have the same spectral indexes as those of the TeV measurements.
‣There is no significant break in the spectrum of HESS J1800−240A.

Table: Power-law spectral indexes and test statistics for the LAT sources in the 2–100 GeV band.

Name	Index[a] (stat) (sys)	TS
HESS J1800−240A	$2.12 \pm 0.23 \pm 0.14$	37
HESS J1800−240B	$2.45 \pm 0.19 \pm 0.07$	88
HESS J1800−240C	$2.38 \pm 0.23 \pm 0.17$	51
Source W	$2.06 \pm 0.20 \pm 0.14$	41

Spectral Modeling with CR escape scenario

Assumptions

- CR start escaping when the SNR enters into the Sedov phase (~310 yr).
- CRs are gradually released from the expanding shell of the SNR, starting with higher energies.
- Spatial distribution function of the escaped CRs (Ohira et al. 2011)

$$n(p,r,t) = \frac{N_{\rm esc}}{4\pi^{3/2}R_{\rm d}R_{\rm esc}r}\left[e^{-(r-R_{\rm esc})^2/R_d^2} - e^{-(r+R_{\rm esc})^2/R_d^2}\right]$$

r: distance from the SNR center to the MC, R_d: diffusion radius of CRs
R_{esc}: the SNR radius when CRs at given energy are released (~2.4 pc)

Rd is proportional to square root of the diffusion coefficient of CRs D_{ISM}.

$$D_{\rm ISM}(p) = 10^{27} D_{27}\left(\frac{p}{10\ {\rm GeV}c^{-1}}\right)^{\delta} {\rm cm^2\ s^{-1}}$$

*Parameters indicated with red marks are free in the modeling.

All spectra can be represented by a single model!

-Total energy of escaping CRs is larger than 2×10^{49} erg
-Support the scenario that SNRs are the main accelerator of CR.

-Smaller diffusion coefficient of CRs than that in the interstellar space

Obtained diffusion coefficient		Values of CR propagation model	
$0.5<D_{27}<1$	<	$D_{27}\sim10$	(e.g., Ptuskin et al. 2006)
$0.1<\delta<0.35$		$\delta\sim0.6$	

✦Possible explanations of the suppression

D_{27} ‣Disturbed by dense environment (Ormes et al. 1989, Gabici et al 2007)
‣Amplification of the Alfvén wave generated by the escaping CRs (Fujita et al. 2011)

δ ‣Harder spectral index than 2.0 for the CRs accelerated in W28, caused by the non-linear shock modification??

More details are available in Hanabata et al. 2014, ApJ, 786, 145